

*Assessment, Repair and Rehabilitation of Lifelines: Highway, Sewage Pipeline and Common Utility Duct*, Koichi Yokoyama, Director, Earthquake Disaster Prevention Research Center, Public Works Research Institute, Ministry of Construction

# ASSESSMENT, REPAIR AND REHABILITATION OF LIFELINES

- Highway, Sewage Pipeline and Common Utility Duct -

by

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## Abstract

Lifelines are one of the most important component in the urban area for supporting social/ economical activities during/ after an earthquake. Direct damage developed on lifelines would effect on not only regional living environment but also nationwide social/ economical activities. Highway facilities, sewage pipelines and common utility ducts which are administrated by Ministry of Construction are defined as lifelines in this manuscript.

In Japan and U.S., lifelines suffered direct/ indirect damage by recent major earthquakes such as 1983 Nihon-kai Chubu Earthquake, 1993 Kushiro-oki Earthquake, 1989 Loma Prieta Earthquake and 1994 Northridge Earthquake. Continuous efforts for upgrading the durability of lifelines have been conducted in both countries.

Especially in Japan, based on the catastrophic disaster caused by 1995 Hyogo-ken Nanbu Earthquake, seismic design standards for most urban facilities initiated to be revised and newly developed to improve the seismic performance. There are requirements for lifelines, as the important component in the urban area, to make technological/ political efforts on design standard, assessment and strengthening.

The U.S.-Japan partnership should conduct cooperative research activities on following subjects;

- (1) Earthquake ground motion for seismic engineering
- (2) Seismic design standards of lifelines
- (3) Seismic assessment and strengthening of lifelines
- (4) Disaster information systems for emergency response

Cooperative research activities on disaster prevention technologies for lifelines have been conducted under the auspices of the U.S.-Japan Joint Panel on Wind and Seismic Effects. Activities on these 4 subjects would be mainly conducted by above mentioned organization.

## I. Topic Description and Policy Issues

Lifelines suffered damage by recent major earthquakes in Japan. 1983 Nihon-kai Chubu

Earthquake caused severe damage on sewerage pipelines. Interruption of highway networks developed by 1995 Hyogo-ken Nanbu Earthquake caused difficulty of evacuation/ restoration in regional scale, and caused indirect damage of social/ economical activities in nationwide scale.

Lifelines are one of the most important component in the urban area for supporting social/ economical activities. Direct damage developed on lifelines would affect not only regional living environment but also nationwide social/ economical activities. Experiences in recent earthquakes show of great importance to maintain lifelines be functional during/ after earthquakes for minimizing earthquake losses.

Based on the catastrophic disaster caused by Hyogo-ken Nanbu Earthquake, reduction of vulnerability is urgently required on most facilities in the urban area. This would be achieved by upgrading seismic safety of facilities themselves and upgrading their emergency management. As one of the most important component in the urban facilities, technological and political efforts would be urgently required on lifelines.

Also in the U.S., continuous efforts for reduction of vulnerability have been conducted on lifelines based on the recent disaster caused by 1989 Loma Prieta Earthquake and 1994 Northridge Earthquake. To achieve the requirements efficiently and economically in both countries, collaborative activities would be effective on the following subjects.

- (1) Reduction of direct damage on lifelines is important for the reduction of vulnerability in the urban area. This requires technological research efforts on the earthquake ground motion for seismic engineering, seismic design standards and seismic assessment/ strengthening.
- (2) Reduction of indirect effects on social/ economical activities developed by direct damage on lifelines is important. This requires technological research efforts for administrators' emergency management on lifeline networks, such as upgrading of disaster information systems.
- (3) Accomplishments of above mentioned research efforts should be reflected on the regional planning and administrators' practices. This requires political encouragement including public policies, mechanisms and incentives to the private and public organizations.

## II. Background

The technological/ political background on each research issues are as follows;

- (1) Earthquake ground motion for seismic engineering

The seismic design, which was for the first time implemented into the regulation of the design of highway bridges in 1926 after 1923 Kanto Earthquake ( $M_r=7.9$ ), has been

revised many times based on research results of the seismic engineering and the investigation of damage caused by earthquakes.

The seismic coefficient  $kh$ , which was not defined specifically in 1926, was set  $kh=0.2$  in 1939 and, in 1956, it was set within the range of 0.1 - 0.35 depending on the regions and ground conditions. It should be noted that between 1939 and 1956, several huge earthquakes such as 1942 Nankai Earthquake ( $M_J=8.1$ ) and 1948 Fukui Earthquake ( $M_J=7.1$ ) developed destructive damage. The investigation of severe damage caused by 1964 Niigata Earthquake ( $M_J=7.5$ ) was taken into consideration, when, in 1971, the seismic coefficient was set  $kh=0.05$  - 0.3 depending on the natural period of the structures, etc. Reinforced concrete bridges seriously damaged in 1978 Miyagiken-oki Earthquake ( $M_J=7.5$ ) triggered various changes in the seismic design of the bridges and the seismic coefficient was raised to  $kh=0.1$  - 0.3 in 1980. In the revision of the specifications in 1990, the check of ultimate strength of RC piers during earthquakes was adopted. In that check, the seismic coefficient was assumed  $kh=0.7$  - 1.0.

1995 Hyogoken-nanbu Earthquake caused unprecedented damage to various structures. And now the drastic change in seismic design is expected, in which the seismic coefficient as high as 2.0 for the check of ultimate strength is employed as the seismic design force considering the near-field huge earthquake.

So far, the seismic design load for the highway bridge was briefly reviewed as the typical example of the lifelines. The underground structures, however, is also important as the lifelines and the seismic design force for them is also quite high. The ground motion considered in their seismic design, reaches 0.4g in peak horizontal acceleration.

As described above, the seismic design force and the input motion for seismic design have been modified. It should be emphasized, however, that further improvement is required and that for that purpose research based on not only civil engineering but various fields including seismology, earth science and geology is essential, such as : the estimation of the ground motion using the fault model, and the seismic hazard analysis based on the geological information of active faults.

## (2) Seismic design standards of lifelines

### 1) Highway bridges

Some highway bridges suffered serious damage by the 1995 Hyogo-ken Nanbu Earthquake. Many reinforced concrete columns suffered damage in shear at the terminated points of main reinforcement at the mid-height. They were designed by the pre-1980 design specifications. The anchorage length of main reinforcement at terminated points was inadequate at those days. Local buckling of web and flange plates progressed to result in rupture of welding at corners in rectangular steel columns.

Research subjects were pointed out to be conducted, such as evaluation of dynamic strength and ductility for structural members, application of dynamic response analysis, development of bearing systems which behave as a major segment of whole bridge, development of new devices to prevent falling-down, re-evaluation of a seat length, effects of liquefaction and lateral spreading on whole bridges, and evaluation of seismic safety of whole bridges.

For highway bridges, revision of seismic design specification is now conducting. In addition to the Seismic Coefficient Method, checking method of dynamic strength and ductility will be introduced for reinforced columns, steel columns and foundations so that seismic safety of whole bridges be increased.

## 2) Application of innovative technologies

For the reduction of seismic response, efforts have been made on the seismic isolation, active control and hybrid control technologies.

The high damping rubber bearing was developed for the seismic isolation design. The Menshin design method considering effects of the damping augmentation and the distribution of the lateral force of the superstructure was developed and it was compiled as the "Manual for Menshin Design of Highway Bridges (Draft)(1992)".

The R&D on the hybrid control technology which combined Menshin Design and active control design has been also conducted. The variable damper was developed as one of the hybrid control devices. The damping characteristics of the variable damper is variable depending on the seismic response of structures.

The R&D on intelligent seismic structures using new intelligent materials such as self-diagnosis-materials and self-repairable-materials has been conducted. The objectives are to develop the structure which has the function to correctly judge the damage and which is easy to repair.

## (3) Seismic assessment and strengthening of lifelines

### 1) Highway bridges

Experiences in recent earthquakes show of great importance to increase the seismic strength and ductility of highway bridge system which is fabricated by superstructure and substructure. The seismic design concept should be introduced to the seismic retrofitting of existing highway bridges.

For enhancing the flexural strength and ductility of reinforced concrete columns, a reinforced concrete jacketing and a steel jacketing are effective. Research efforts have

been conducted on evaluating the flexural strength and ductility of retrofitted columns through loading tests. Application of a carbon fiber sheet has been also examined.

For steel columns, a corner strengthening, additional-rib-welding and infill-concrete casting have been examined.

## 2) Underground utilities

In the 1993 Kushiro-oki Earthquake and 1994 Hokkaido Toho-oki Earthquake, sewage pipelines suffered severe damage by the liquefaction of backfilled and original soils. Manholes floated about 1.5m up to the ground surface and pipes distorted vertically and horizontally in the liquefied soils. These experiences show that liquefaction-induced damage could be catastrophic and is quite difficult to find and recover.

Common utility ducts are one of the most important utilities in the urban area, in which most supply systems are integrated. Nationwide-scale seismic assessment of existing common utility ducts have been conducted in 1991. The screening survey identified the sections considered vulnerable against liquefaction-induced damage. It has been followed by in-depth survey and strengthening planning.

Disaster caused by 1995 Hyogo-ken Nanbu Earthquake lead public works related organization to increase the seismic performance level of most lifelines. However damage mechanisms, assessment and reinforcement techniques for underground utilities have been studied supposing moderate earthquake, much remains to be studied against more intense earthquake. Public sectors' commitment to improve seismic performance of underground utilities strongly depend on the development of practical/ economical technologies required to implement. The government organizations should conduct research efforts on identifying lifeline categories that require strengthening, providing assessment/ strengthening technologies against liquefaction, and providing cost-performance/ feasibility evaluation technology.

## (4) Disaster information systems for emergency response

Reduction of direct and indirect earthquake effects requires that existing lifelines be functional following an earthquake. This requires both minimizing damage and planning/ implementing practices for localizing effects of damage on network performance.

Road facility is one of the most sensitive lifeline to the spread of indirect effects because damage on road facilities could directly cause the delay of evacuation, emergency response and social/ economical restoration. For the reduction of indirect effects in both regional and nationwide scale, upgrading of the road network performance is urgently required.

Experiences in recent earthquakes show the efficiency to develop/ implement disaster information systems for supporting administrators' road network management. These systems can realize appropriate risk assessment/ strengthening strategy as a pre-earthquake network management, expeditious damage detection/ restoration strategy as a post-earthquake network management.

Development/ implement of innovative information technologies represented by GIS and GPS are rapidly progressing in various industries. For upgrading road administrators' network management, technological research efforts should be conducted to apply the technologies to the disaster information systems.

### III. Proposal

The U.S.-Japan Earthquake Disaster Mitigation Partnership provides an extraordinary opportunity to reduce both countries' vulnerability to catastrophic earthquake disaster. Moreover, by coordinating research efforts and continuing to learn together from earthquake experiences, Japan and the U.S. develop the required technologies and practices expeditiously and economically.

Cooperative research activities on the following four subjects are important for seismic assessment, repair and rehabilitation of lifelines.

- (1) Earthquake ground motion for seismic engineering
  - 1) Cooperative research with other technical fields such as seismology and geology
  - 2) Research based on large-size experiments
- (2) Seismic design standards of lifelines
  - 1) Seismic design of highway bridges
  - 2) Application of innovative technologies
- (3) Seismic assessment and strengthening of lifelines
  - 1) Retrofitting of highway bridges
  - 2) Countermeasure against soil liquefaction for underground utilities
- (4) Disaster information systems for emergency response
  - 1) Information systems for pre/ post earthquake road network management
  - 2) application of innovative information technologies

### IV. Cooperative Mechanisms

Cooperative research activities on disaster prevention technologies for lifelines have been conducted under the auspices of the U.S.-Japan Joint Panel on Wind and Seismic Effects (WSE), and U.S.-Japan Cooperation in Research and Development in Science and Technology. Fundamental technologies required by both countries have been developed

effectively through professionally classified task committees established in WSE.

Four research activities proposed in this manuscript can be addressed by collaborative efforts of WSE. Enhanced implementation of cooperative research projects and personnel exchange based on public policies will strengthen these collaborations.